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NIRCAM – Filter Wheel

Near-Infrared Wide Field Camera for NGST

NGST – DSS – WHRP – 002

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Work performed under ESA contract for the
"Study of Payload Suite and Telescope for NGST"
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0 INTRODUCTION

As part of its Origins program, NASA is currently undertaking definition and feasibility studies of a Next Generation Space Telescope (NGST) to succeed the Hubble Space Telescope (HST) after 2005. NGST is foreseen to have an aperture of 8 meters and be optimized for near infrared wavelengths (0.6 - 10+ microns) in order to enable the exploration of the most remote high redshift universe.

NASA has invited ESA to extend their successful collaboration on HST to the NGST project, and a draft agreement concept is in place which aims at securing European participation in NGST at a similar level as on HST. ESA has undertaken a number of assessment studies which aimed at defining its potential instrument and spacecraft hardware contributions to the mission.

One of these ESA studies called "Study of Payload Suite and Telescope for NGST" (ref. /1/), has been conducted by Dornier Satellitensysteme GmbH (DSS), Ottobrunn, together with Alcatel Space (AS), Cannes, and a team of 16 European science institutes chaired by Laboratoire d'Astronomie Spatiale, Marseille, and UK Astronomy Technology Centre, Edinburgh. DSS took the responsibility for the overall study and the payload, AS for the telescope, and the science team was responsible for the instrument and telescope definition and requirements.

The **NIRCAM – Filter Wheel** is one of four instruments that were defined by the science team as potential NGST payload and was detailed by DSS.

This document contains the instrument opto-mechanical design and analyses and the instrument specific development planning. Technical aspects that are common to all payloads studied by DSS (NIRCAM-FW, NIRCAM-FTS, MIRCAM, MIRIFS and IFMOS, which was studied under a separate contract) are described in a separate report, ref. /3/. These aspects include

- optical interface
- material selection, mechanisms
- thermal design and analysis
- electrical design, detectors, data processing
- common critical areas

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1 SCIENCE REQUIREMENTS

1.1 The NASA Design Reference Mission (DRM)

1.1.1 DRM overview

The NASA Design Reference Mission has been defined with the goal to identify the most promising science NGST can do, and to help set the science requirements defining the instrument payload. A large fraction of the NGST mission is a core program, designed to understand the origin and evolution of galaxies, mapping dark matter, measuring cosmological parameters and study the physics of star formation. The DRM also includes a range of other studies which fall within the NASA Origins program. The studies in the DRM are being defined to a level of detail which includes the number density and brightness of potential targets, the number of observations needed and the desired observing modes. The DRM has been divided into five broad science areas: Cosmology and the Structure of the Universe; Origin and Evolution of Galaxies; The History of the Local Universe; Birth of Stars; Origin and Evolution of Planetary systems, the main programs are listed in Table 1.1-1. The goal is for the NGST to be capable of accomplishing the studies in the DRM in less than 3 years.

Rank	Score	SDM	DRM Title
1	1.9	0.4	Form. & Evol. Galaxies- Imaging
2	2.9	0.4	Form. & Evol. Galaxies- Spectra
3	6.2	0.9	Mapping Dark Matter
4	6.8	0.8	Searching for the Reionization Epoch
5	7.3	0.9	Measuring Cosmological Parameters
6	7.8	1.0	Form. & Evol. Galaxies- Obscured Starform. &AGN
7	8.4	1.0	Physics of Star Formation: Protostars
8	10.5	1.0	The Age of the Oldest Stars
9	11.3	1.4	Detection of Jovian Planets
10	11.8	1.5	Evolution of Circumstellar Disks
11	12.0	1.5	Measuring the Rates of Supernovae
12	12.1	1.1	Origins of Substellar Mass Objects
13	12.2	1.2	Form. & Evol. Galaxies- Clusters
14	13.9	1.3	Form. & Evol. Galaxies near AGN
15	14.1	0.8	Cool Field Brown Dwarf Neighbors
16	14.6	1.1	Survey of Trans-Neptunian Objects
17	16.0	1.4	Properties of KBOs
18	16.8	1.0	Evolution of Organic Matter in ISM-Astrobiology
19	17.0	1.1	Microlensing in the Virgo Cluster
20	17.0	0.9	Ages and Chemistry of Halo Pops.
21	17.6	0.9	Cosmic Recycling in the ISM
22	18.5	0.8	IR Transients from GRBs and Hosts
23	18.7	0.9	IMF for Old Stellar Populations

Table 1.1-1: Ranked list of DRM programs (from NASA-ASWG). The core programs 1-7 are shaded

Many programs require a wide field camera working in the range 0.6 to 5 microns, taking as much as 25% of the total observatory time, or more. We give the general outline of some programs below.

1.1.2 *Cosmology and the Structure of the Universe*

Measuring the distribution of dark matter in the universe is crucial for understanding the evolution of structure since the Big Bang, and for understanding the nature of dark matter. By using weak gravitational lensing techniques to analyse ultra-deep multi-band images the dark matter distribution can be determined on scales ranging from individual galaxies, through groups and clusters up to the large scale (>3Mpc) matter distribution. The combination of imaging observations and spectroscopic information on the brightest members will allow to investigate the relationship between dark and visible matter on large scales.

NGST will be uniquely capable of both discovering and obtaining spectroscopy for distant supernovae (SN) at redshifts of 2-4. Type 1a supernovae can be used as standard candles to directly study the geometry of the universe. q_0, Λ and Ω can be determined from measurements of apparent magnitude as a function of redshift, and as the redshifts get higher the magnitude difference differentiating cosmological models increases, and thus supernovae at redshifts 2-4 will yield more definitive cosmology results than ground based surveys. In addition finding the “turn-on” redshift of type 1 SN from deep searches is important for understanding the chemical evolution of galaxies since they are the major source of iron production. Deep wide field imaging will play a key role to identify the distant SN.

1.1.3 *Origin and Evolution of Galaxies*

The goals of these programmes are to find the first generation of stars and quasars. Deep imaging surveys in the near-IR will allow to study galaxy formation and evolution for field and cluster galaxies, the effects of AGN on chemical evolution and to understand the nature of gamma ray burst sources. In the same way the Hubble Deep Fields have been instrumental in pushing our limits, a few deep fields with NGST will again open new areas of investigation.

Deep observations with NGST are uniquely suited to identifying sources at redshifts of z>10 through their Lyman-alpha break at wavelength 1.2[(1+z)/10] microns. This is an important test because various models for structure formation make similar predictions about the local universe but differ significantly in their predictions of the number and distribution of sources at very high redshifts.

The deep imaging surveys are aimed at determining photometric redshifts and morphologies of galaxies. The formation of disks and population II halos can then be traced to high redshifts to study the importance of merging, the relative roles of gravity, dissipation and energy injection on different scales and the interaction between galaxies and the IGM.

1.1.4 Clustering and Proto-Clusters in the Early Universe

Understanding the formation and evolution of large scale structures is a long time quest for cosmology. While we have made significant progress and more is expected with the 8-10m class ground based telescopes, the question of the early formation of the most massive structures will remain a cornerstone of cosmological investigations until a complete picture is drawn.

On the largest redshift surveys in our local universe, there is convincing evidence that the distribution of galaxies is inhomogeneous on all scales smaller than 100 Mpc. The distribution remains strongly inhomogeneous even out to z~1, with galaxies distributed in another density peaks and empty regions (”picket-fence” distribution).

At redshifts beyond 1, very little is known about large scale structures. Only a few large structures have been identified so far. Significant clustering of galaxies has been observed at z~3, still within the predicted range of models such as the CDM. At these redshifts, the prevalence of clusters, proto-clusters, or other large scale structures in the distribution of galaxies, is as yet unknown, and the evolution of structures may well be in a critical stage, where observations can directly constrain cosmological models. It is most probable that the early phases of large scale structures assembly will still remain to be explored after the work from the 8-10m ground based telescopes has levelled down. This is where the NGST is expected to play a unique role.

The goals of this programme are (i) to study the site of formation of clusters of galaxies, “proto-clusters”, to establish the morphological and dynamical properties of proto-cluster cores, and of the galaxies in them, and (ii) to establish the clustering properties of the distribution of galaxies at redshifts much larger than 3. The study of ~100 (proto-) clusters at high redshifts z>3, will be best done from integral field spectroscopy in a field comparable to the proto-core dimensions, on order 1 arcmin. The study of the clustering properties of galaxies at earlier epochs will be best done from a sample of several tens of thousand redshifts of galaxies, best obtained with a wide field spectrograph with a high multiplex factor (number of simultaneous objects observed) such as the IFMOS wide field instrument.

1.1.5 The History of the Local Universe

The studies of the history of the local Universe are based on the determination of the low-mass end of the IMF in globular clusters, very nearby galaxies, chemical evolution of halo populations, the IMF of old stellar populations and the ages of stars in local group galaxies. All require the highest spatial resolutions possible and accurate optical/near-IR photometry.

While massive star-formation can readily be observed from the ground to high red-shifts, low mass stars are currently invisible at distances beyond the LMC. However low mass stars constitute most of the mass and structure of galaxies. The greater sensitivity and resolution of NGST means that it will be possible to determine whether the oldest stars in M31 have the same ages as those in our galaxy. Detections at R~31 can reach a 15Gyr old main sequence turnoff out to distances of 1 Mpc. Very long exposures would be capable of establishing ages for the oldest stars in M81 and NGC 5128. By pushing NGST to the confusion limits in the I band it will be possible to study old stellar populations in tidal tails and between galaxies, potentially enabling us to determine a history of mergers in clusters since their formation.

The age of the oldest stars in our galaxy could be determined by using deep high resolution near-IR imaging to determine the absolute magnitude of the end of the white dwarf cooling sequence in nearby globular clusters. Such studies are important because they would be the first measurements of the stellar ages which are independent of the main sequence turn-off and stellar evolution theory.

1.1.6 Birth of Stars

The studies of the birth of stars included in the DRM are concerned with probing the IMF in star formation regions with a view to determining the origin of distribution of stellar masses. The goal is to compare the low-mass end of the IMF in regions found to be forming stars under a variety of different physical conditions. NGST with its combination of high spatial resolution and low thermal background will be able to sample the emergent mass distributions in young clusters down to planetary mass objects out to 1kpc. Infrared imaging combined with multi-object spectroscopic follow-up will be used to determine whether or not the IMF is universal down to the minimum mass for molecular cloud fragmentation and to characterise the shape of the IMF for 1-20 Jupiter masses i.e. the boundary between planets and stars.

1.1.7 Origin and Evolution of Planetary Systems.

Studies of the origin and evolution of planets in the DRM include studies of the Kuiper belt objects in our solar system, direct imaging of planets around nearby stars, and the study of debris disks around stars and proto-stars.

NGST can observe low mass stars in star forming regions out to several kpc, providing the first opportunity to study the detailed properties of proto-planetary disks as a function of age, stellar mass and environment. Combining both near and mid-IR spectroscopy is important to understand the distribution and evolution of the dust and gas in proto-planetary disks. Dust grain sizes, compositions and ice mantles could be studied as a detailed function of radius, vital information for understanding the formation and composition of gaseous planets. For older stars in which active accretion has ceased, mid-IR measurements are essential for the study of optically thin dust disks, the precursors of β-Pic type systems.

A coronographic capability coupled to a near IR camera would allow to search for Jupiter – like planets around stars within 10pc. This is described elsewhere.

1.2 Near-IR Camera Technical Specifications

This instrument is expected to be one of the most used instruments. It will produce the deepest images to be obtained with NGST, with high scientific return and deep visual impact which could reach far in the minds of the general public. We stress that this camera requires the largest number of pixels possible. The issue of spatial sampling vs. field is a delicate balance with a difficult compromise to reach if the instrument is to remain simple and reliable.

1.2.1 Instrument Performance Requirements

The main drivers for NIRCAM are:

- access to the full wavelength range 0.6 to 5 microns
- a large field of view
- a spatial sampling matched to the diffraction limit

The final high level technical specifications are given in Table 1.2-1.

Instrument	Item	Specification
NIRCAM	Wavelength Range	0.6-5µm
	Field of View	> 16 arcmin²
	Spatial sampling	0.04 arcsec/pix
	Filters	Broad band (JHK…) Narrow band: Selected list (required) Any CW (goal)
	PSF	Stable at better than 1% level
	Distortion	Ability to correct / remove at the $3x10^{-5}$ level
	Detector readout	Non destructive readout

Table 1.2-1: NIRCAM high level technical specifications

The wavelength range has been set to go down to 0.6µm with the same set of detectors. This offers a simple way to expand the NGST capabilities toward the visible domain.

As always, the balance between the field size and the pixel sampling is difficult to achieve. It was felt that a pixel sampling of 0.03 arcsec/pix was more appropriate than 0.04 arcsec/pix for the lower wavelength. However, oversampling would occur at the high wavelength range.

One solution would be to employ zoom optics to change the pixel scale depending on the science requirements vs. the wavelength range. For this preliminary phase we set simplicity as a requirement, hence only one fixed camera with one pixel scale has been selected. We have set the sampling to obtain critically sampled images at 2.5μm.

Filters requirements include a set of broad band very efficient filters. Science requirements also call for a set of narrow band filters. Ideally, these should have any central wavelength with a bandwidth corresponding to R~50. Tuneable filters based on a Fabry-Perot could satisfy this requirement. However, again satisfying our simplicity requirement, we have specified a set of narrow band filters with fixed central wavelength and bandwidth as the minimum requirement.

1.2.2 Instrument Operations

The NIR-IR Camera should have the following modes of operation

Simple Imaging

In this mode a broad or narrow band filter is selected and data are obtained with it.

Imaging Surveys

In this mode a broad or narrow band filter will be selected.

The telescope may be stepped through several positions with data taken at each position in order to map a larger area than the field of view for surveys or very extended sources. The need to use stitching techniques to create large mosaic images imposes a stringent requirement on the ability to remove any optical distortion.

Depending on the stability of the NGST thermal background it may be desirable to implement deep surveys using a "drift scanning" technique.

Common for both imaging modes:

- repeated observations will be summed to achieve the desired signal to noise.
- jittering and "drizzling" techniques may be used to ensure the best spatial resolution, and remove bad pixels.

Flat Field Calibrations

The flat field will be determined from the median of a jittered set of sky observations taken with the appropriate filter selected.

Photometric Calibrations

These calibrations will be determined from observations of stars of known magnitude.

PSF Calibrations

Calibration of the point spread function (psf) will be obtained from observations of point sources.

2 ENGINEERING

Note: details on mechanical, thermal and electrical design can be found in ref. /3/.

2.1 Design Concept

2.1.1 Optical Design Description

The optical configuration of the Filter Wheel Camera is based on the scientific requirements of Table 1.2-1 and shown in Figure 2.1-1. It is a symmetric all-reflective design (apart from the folding mirrors), and consists of the following functional units

- collimating optics
- filter wheel optics
- imaging optics

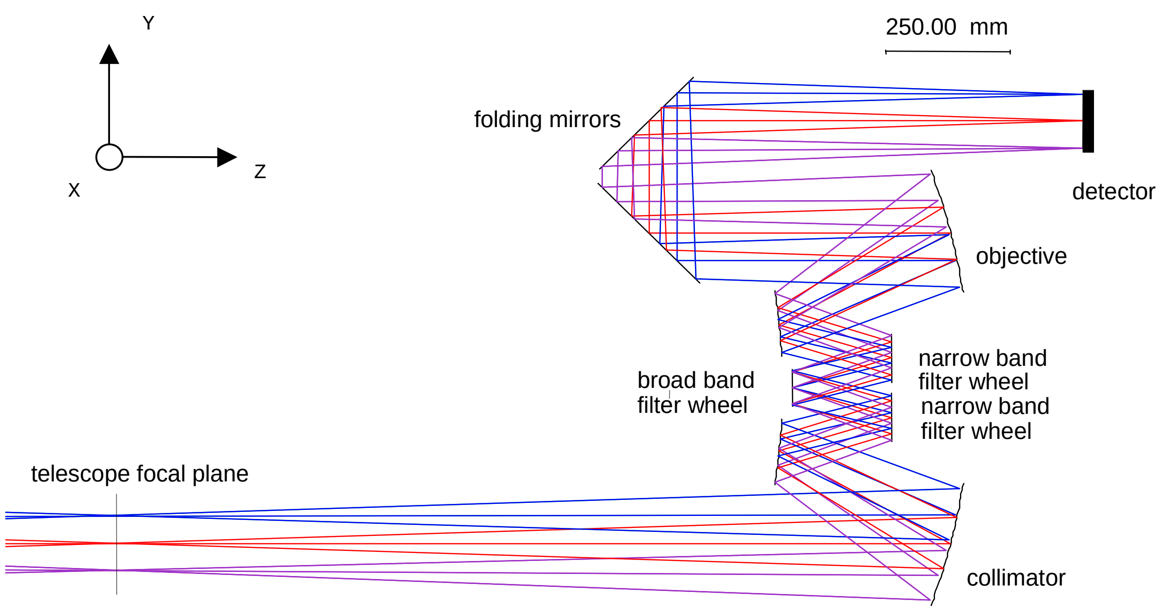


Figure 2.1-1: Optical configuration of NIRCAM-FW

The collimating optics is a two-mirror system which provides a parallel beam for the filter wheel optics. The filter wheel optics consist of a set of filters used in reflection. (Note: this design has been optimized for minimum dimensions and mass. Other filter configurations are possible, but the collimating/imaging optics design will change if the number of reflective filters is zero or even.) The filters are accommodated on three filter wheels and are exchangeable by rotation of the filter wheels. The imaging optics are the mirrored version of the collimating optics and focus the beam onto the detector.

Two folding mirrors arranged under an angle of 45° with respect to the beam are used to get the focal plane close to the optics on the common baseplate. These two mirrors are mechanically connected and movable by means of a refocusing mechanism to focus the beam on the detector array, if necessary after cool-down.

The entrance pupil and the exit pupil are both telecentric. The aperture stop is formed at the broad band filters located on the second filter wheel on the axis of the optical system. The design parameters of the optical system are summarized in Table 2.1-1.

Design parameters of NIRCAM-FW	
Parameter	**Value**
Wavelength range	1 to 5 µm
Reduction ratio	1
F-number at object side	16
Field (arcmin)	6’ x 3’
Detector array size	12K x 6K
Pixel size	18.5 µm
IFOV	0.14 µrad (or 30 mas)
Entrance pupil	telecentric
Exit pupil	telecentric
Stop	at second filter wheel
Stop diameter	72 mm
Spectral Filters	3 filter wheels with 24 filters in parallel beam after collimating optics

Table 2.1-1: NIRCAM–FW design parameters

Collimating and Imaging Optics

The collimating optics and the imaging optics are identical tele-objectives with a focal length of 1100 mm, consisting of one large spherical and one smaller aspherical decentered mirror. The aspherical mirror is not critical with respect to manufacturing.

Filter Wheel Optics

The filter wheel optics are located in the parallel beam between collimating and imaging optics and consist of three filter wheels. There are 8 broad band and 16 narrow band reflective filters. The broad band filters are standard astronomical filters in the range from 0.6 to 5 µm. The narrow band filters operate in the range from 1 to 5 µm with a typical bandwidth of 1% (see Table 2.1-2).

	Filters	Filter bandwidths
Wheel 1	8 narrow band + 1 blank	~ 1%
Wheel 2	8 broad band + 1 blank + 1 "black"	~ 20%
Wheel 3	8 narrow band + 1 blank	~ 1%

Table 2.1-2: Filter wheel optics

The blank positions are broad band reflective mirrors. The "black" position is of high emissivity, providing a quasi-zero input photon flux at operating temperature, and is intended for calibration purposes.

Based on scientific needs, the broad band filters shall have a typical width of about 400 nm at the center of the wavelength range, a roll-off of the wings of about $0.025/nm^{-1}$ and a mean transmission of about 90%. In the same range the small band filters shall have a typical FWHM of 20 to 40 nm, a roll-off of the wings of about $0.15/nm^{-1}$ and a peak transmission above 70%. Outside the bands the filters shall block the radiation to a level of 10^{-5} (tbc).

With these requirements pure reflective filters do not seem feasible, as they would have a rest reflection of at least 5 to 10% and in addition many parasitic lines in the blocking area outside the spectral band. This is valid for small band as well as broad band filters and inherent to the principle of reflective filters, that are composed of many quarter wave layers.

Therefore, for astronomic applications filters are normally used in transmission. These filters, that are based on the Fabry-Perot principle, do have a very small rest reflection in the blocking area outside the specified spectral band.

The principle of using transmission filters in the reflective setup of Figure 2.1-1 is shown in Figure 2.1-2. Again, the optical design of Figure 2.1-1 can be adapted for the use of pure transmission filters, but this will then increase the instrument dimensions and lead to a somewhat more complex optics design (see optics design of ref. /4/).

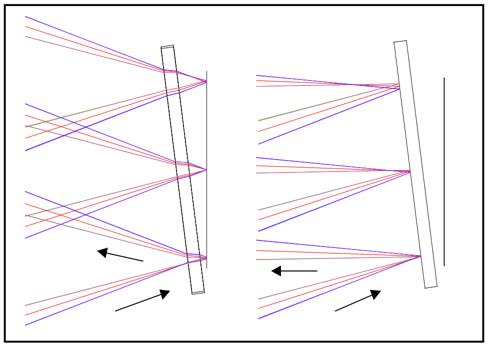


Figure 2.1-2: Use of transmission filters in reflective setup (left: in-band transmission; right: out-of-band rejection)

2.1.2 Optical Performance

Image quality and MTF

The optical performance is diffraction limited. The wave-front errors and Strehl ratios of the field center position and the extreme field positions are given in Table 2.1-3.

Wavefront error of NIRCAM-FW and Strehl ratios calculated for a wavelength of 1 µm.			
Relative field position (X, Y)		Wavefront rms	Strehl ratio
0	0	0.025	0.98
1	1	0.036	0.95
-1	1	0.036	0.95
1	-1	0.046	0.92
-1	-1	0.046	0.92

Table 2.1-3: NIRCAM – FW wavefront errors and Strehl ratios

The MTF as a function of frequency is given in Figure 2.1-3. At all field positions the MTF is close to the diffraction limit. The MFT as a function of defocusing (through-focus MTF) for a spatial frequency of 15 cycles/mm is given in Figure 2.1-4. A defocusing of 0.25 mm will result in a maximum decrease in MTF of about 13%.

Figure 2.1-5 shows the spot diagrams of the images at the center and the corners of the field. Figure 2.1-6 shows the geometric aberrations.

The field angles of all figures are expressed in relative coordinates w.r.t. the maximum field angles.

Transmission

The optical transmission is wavelength dependent – the lowest transmission is expected at the shortest wavelength. At 1 µm wavelength the following reflectivity figures are assumed:

- mean reflection of a gold coated mirror: 0.98
- mean reflection of a narrow band filter: 0.70
- mean reflection of a broad band filter: 0.93

In the broad band mode the camera contains 8 mirrors and the broad band filter, and in narrow band mode 7 mirrors and the narrow band filter in combination with the corresponding broad band filter (to suppress out-of-band features). Then the mean overall transmission of the camera optics at 1 µm is:

Broad band: T ~ 0.81

Narrow band: T ~ 0.58

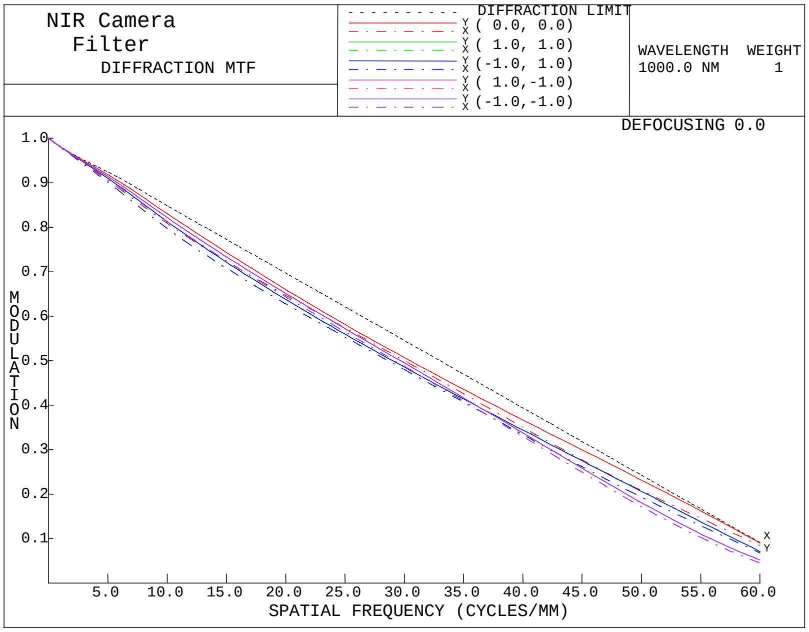


Figure 2.1-3: NIRCAM-FW: MTF as a function of spatial frequency, calculated in the center and the corners of the field.

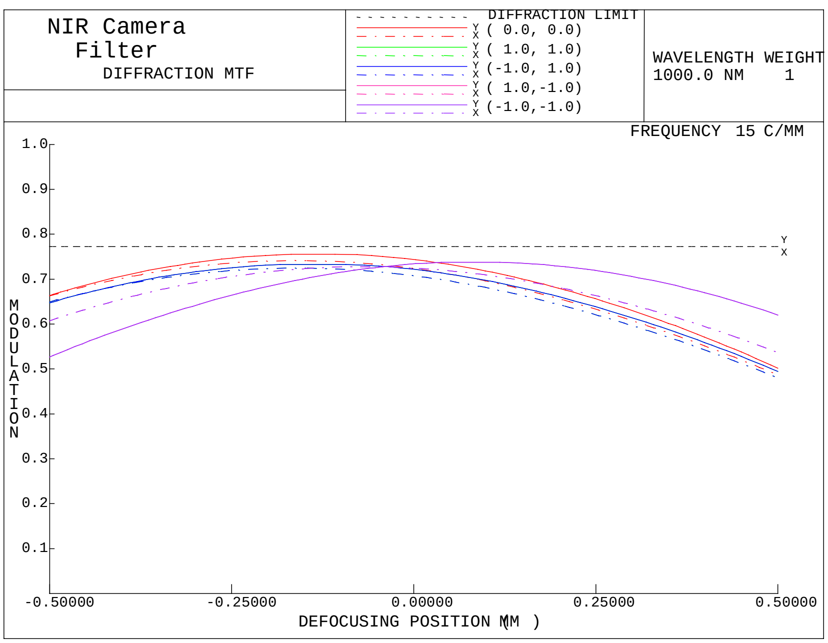
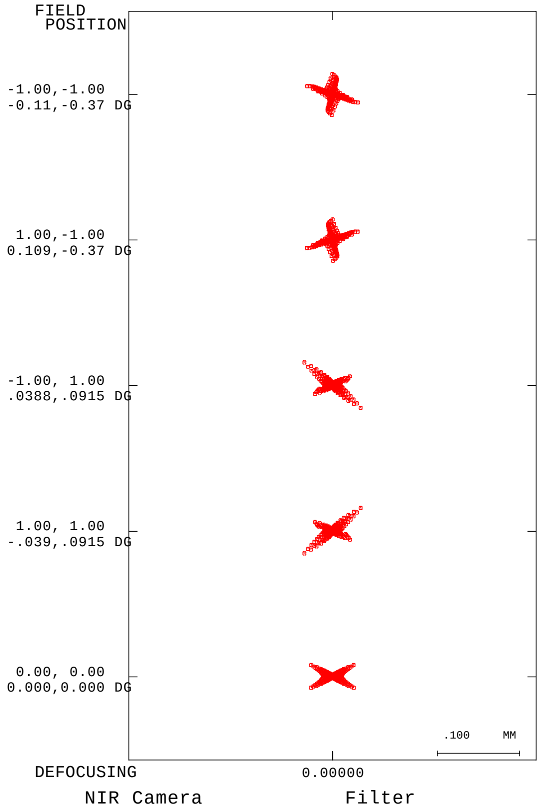


Figure 2.1-4: NIRCAM-FW: through-focus MTF calculated in the center and the corners of the field for a frequency of 15 cycles/mm.



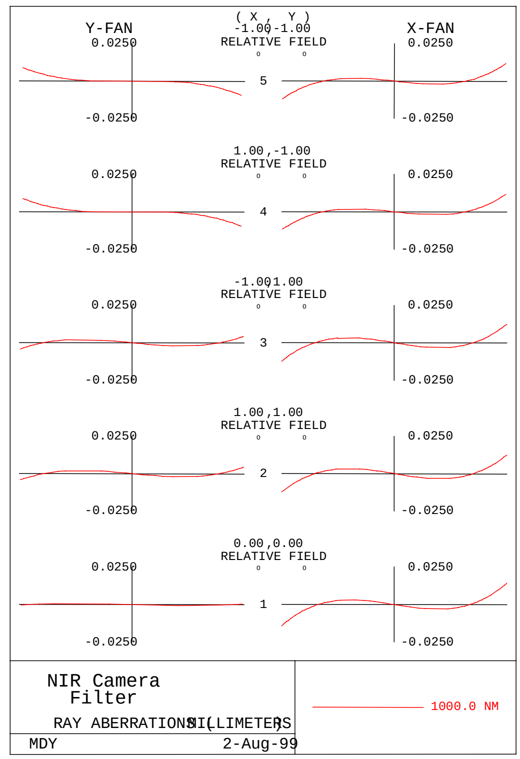


Figure 2.1-5 (left): NIRCAM-FW: spot images at the center and the corners of the field.

Figure 2.1-6 (right): NIRCAM-FW: lateral ray aberrations in the center and the corners of the field.

2.1.3 *Photometric Performance*

A photometric performance model has been established to simulate the expected in-orbit instrument performance. The model includes all efficiencies from the telescope transmission up to the detector quantum efficiency. As photon background the expected zodiacal light (ref. /5/) has been considered.

Figure 2.1-7 shows the magnitudes of point objects as a function of wavelength that can be resolved in broad and narrow band imaging mode for 10^5 sec observation time and a Signal-to-Noise-Ratio (SNR) of 10.

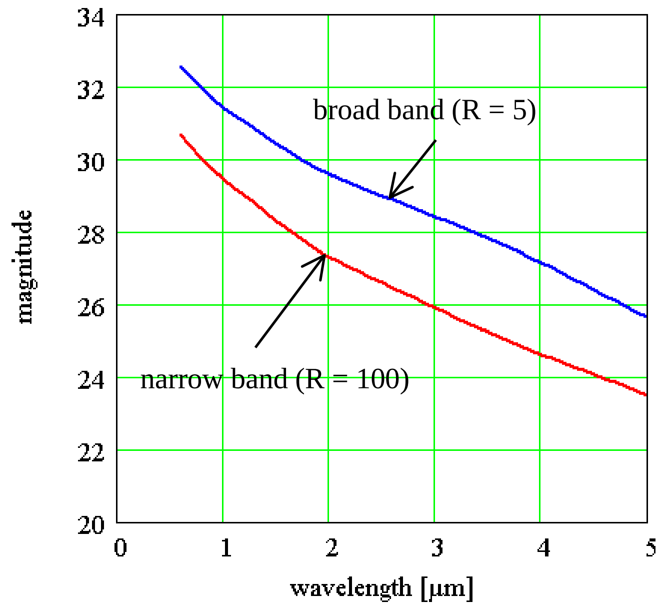


Figure 2.1-7: detectable magnitude of point sources vs. wavelength that can be resolved with an SNR of 10 in broad and narrow band imaging mode for an observation time of 10^5 sec (ordinary magnitudes!)

Discussion of Results

The performance of the broad band operation mode is for all target magnitudes photon noise limited. In the faint object limit of Figure 2.1-7 the zodiacal light is the dominating noise source. The detector and the readout noise are negligible.

In the faint object limit of the narrow band imaging mode the detector noise is of the same order than the zodiacal light: In the spectral regions of higher zodiacal light the performance will just be photon noise limited, whereas at wavelengths of lower zodiacal light (from around 2.2 – 4.5 µm) the performance will be detector noise limited. Readout noise is negligible (assuming Fowler sampling).

2.1.4 Opto-mechanical Design

The baseline opto-mechanical designs are shown in Figure 2.1-8 and 2.1-9.

The optical bench as primary structure consists of a light-weighted plate made of C/SiC material. The C/SiC brackets for the optical components are directly attached to the baseplate. The mirrors are connected to the brackets by an isostatic 3 point support. Flexible INVAR mounts are used as connection elements.

The two folding mirrors are mounted on a separate C/SiC plate which can be moved by a mechanism for optics refocusing.

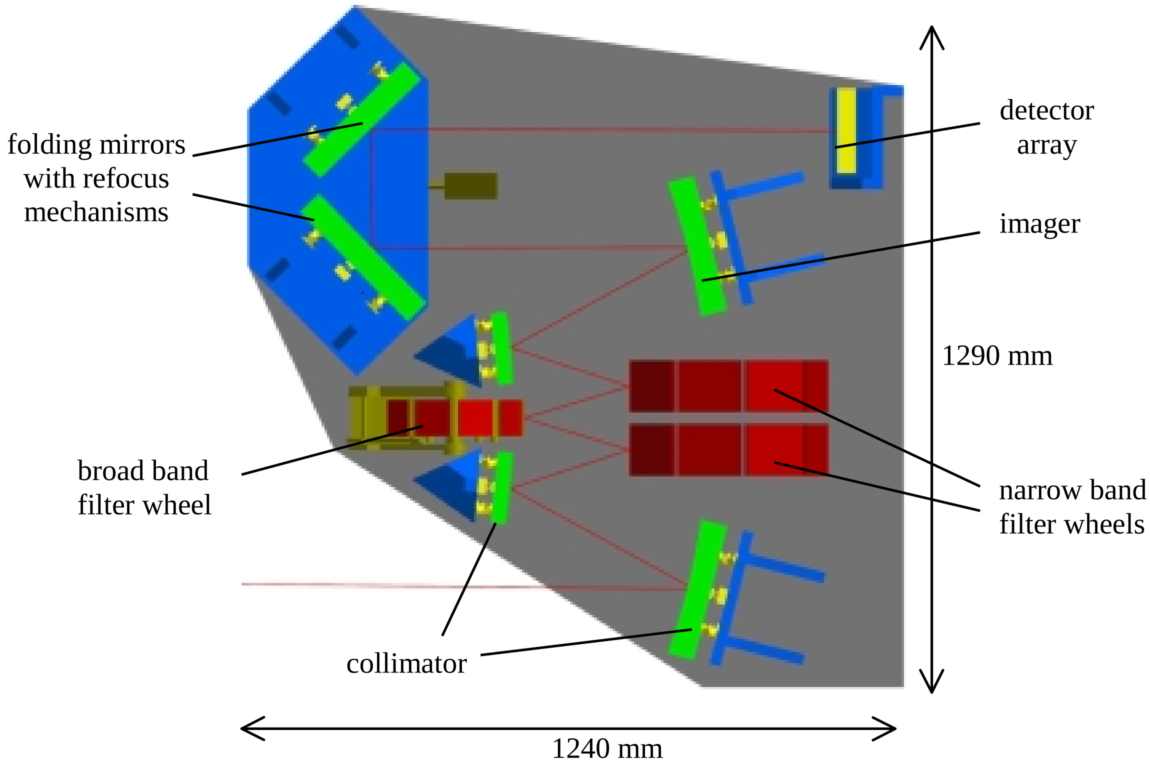


Figure 2.1-8: NIRCAM - Filter Wheel design: top view

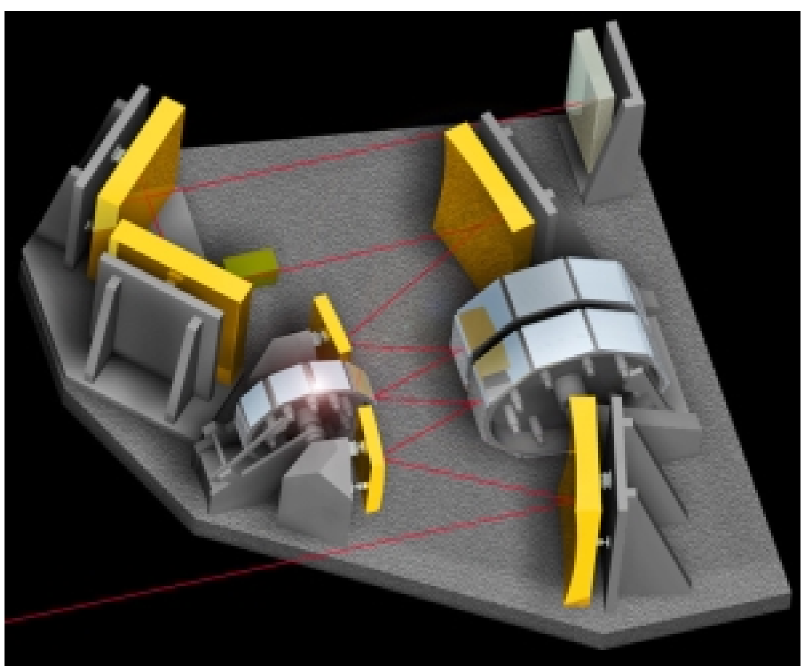


Figure 2.1-9: NIRCAM - Filter Wheel design: 3D view

2.1.5 Budgets

The overall dimensions are: 1.30 x 1.24 x 0.47 m^3

The estimated overall mass of the Filter Wheel Camera is 62 kg (Table 2.1-4).

	Mass [kg]
Primary structure	20
Brackets, mounts, filter wheels	15
Optical components	16
Mechanisms	1
Miscellaneous (I/F brackets, harness, etc.)	10
Total	**62**

Table 2.1-4: NIRCAM Filter Wheel mass budget

2.1.6 Conclusions

The Near Infrared Filter Wheel Camera is a very compact instrument, considering the wide field of view. The optical system with 1:1 magnification was derived from an Offner relay and presents a simple and elegant design without criticality. The filter wheel optics, however, will require additional engineering effort to minimize the single point failure probability.

The NIRCAM-FW has the following design and performance features:

+ compact and symmetric optical design with only one aspherical mirror, resulting in simple manufacturing, alignment, testing and verification
+ good optical performance
+ good access to the pupil plane, resulting in a compact configuration of the filter wheel optics
+ high efficiency (transmission)
+ full field available for science (separate sensor for telescope pointing control)
- fixed spectral positions and fixed bandwidths of narrow band filters

The following work is recommended for the next study phase:

- filter definition and design
- optics defocusing analysis (review need of an active refocusing mechanism)

2.2 Critical Areas and Recommended Development Activities

2.2.1 Instrument Hardware Breakdown

Figure 2.2-1 shows the HW breakdown of the filter wheel camera. The shaded boxes provide an overview of potential critical subsystems or of subsystems containing critical elements as listed in chapter 2.2.2.

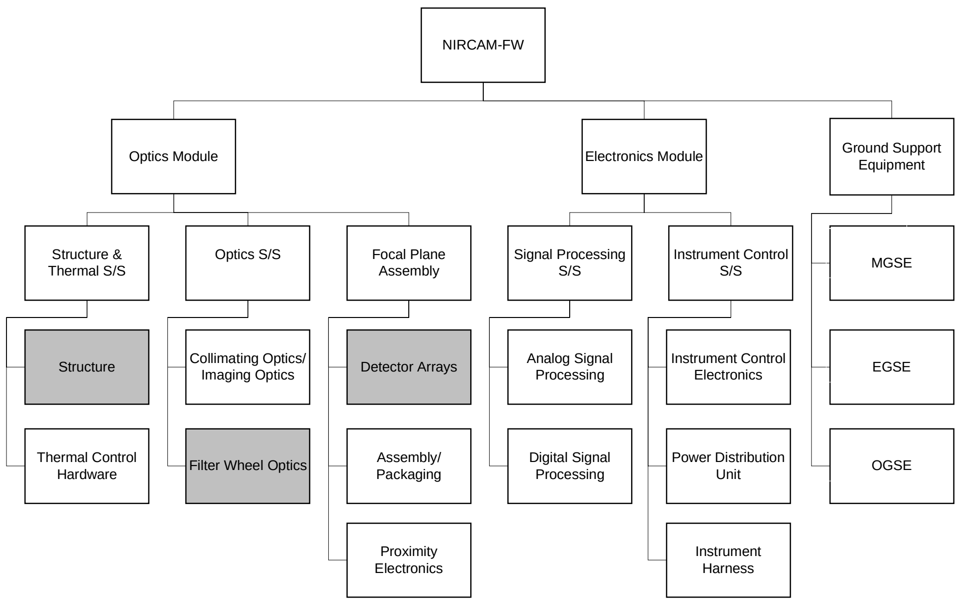


Figure 2.2-1: Instrument Hardware Breakdown; shaded areas indicate potential critical subsystems.

2.2.2 Critical Areas and Technology Requirements

Potential criticalities to be considered during the development of the instruments are

- items whose failing may affect the satellite performance or survival probability
- single point failures and non-redundant major elements
- items whose failing/degradation may affect the instrument performance
- items not previously space qualified
- items with exceptional process sensitivity and long lead items

The critical areas of the NIRCAM-FW are mainly concerned with the last two items, i.e. subsystems which contain new technologies or technologies of expected long development duration. These technologies should be identified in an early stage of the project to allow definition of a dedicated technology development program in order to reduce the development risks of the project.

Critical Areas and Risks

In ref. /3/ a generic list of critical areas had been provided, which is valid for all instruments under consideration. Instrument specific areas of potential criticality for NIRCAM-FW are summarized in the following Table 2.2-1.

Subsystem	Critical area	Comments
Filter wheel optics	filter design, performance and mounting	possible drifts during cool-down, CTE differences
	reliability of filter wheel mechanisms	single point failure criticality of 3 subsequent wheels (2 of them equipped with narrow band filters)

Table 2.2-1: Potential critical areas of NIRCAM-FW

Technology Requirements

The filters have a different CTE than the instrument and the filter wheel structure, and their mounting should be demonstrated in an early stage of the project. These elements need to be mounted in a way which avoids stress during cool-down and which will survive the launch loads.

Low temperature filter wheels have been built, qualified and flown for ISOPHOT, ref. /3/. However, given the importance of the NIRCAM and the fact that there will be a higher failure probability due to three wheels in a row it is recommended to carefully review existing designs for possible improvements and demonstrate the improved reliability by hardware tests.

2.2.3 Recommended Follow-On Activities

Technology Development Activities on Instrument Level

In order to minimize the development risks the following technology development activities are recommended.

- verification of C/SiC material for structural and optical components
- verification of filter wheel mechanisms and filter mounting technology

For each of these activities, the following technology development activities are proposed:

- critical review of existing technologies
- design and manufacturing of a representative unit
- verification of performance prior to and after environmental tests, at ambient and at operating conditions

The expected duration of the development activities is 15 months.

Technology Development Activities on System Level

There are other technology verification activities which are considered necessary, especially the developments of the detectors and mechanisms for refocusing. But these technologies will be needed for other NGST hardware units as well and it is assumed that they will be developed on system level (under NASA contracts).

2.2.4 Technology Development Roadmap

The technology development roadmap for the major critical technologies is depicted in Figure 2.2-2 below.

The instrument specific hardware elements which are recommended for technology development are

- C/SiC material at cryogenic conditions
- filter wheel mechanisms and filter mounting

The system level hardware elements that are recommended for technology development are (corresponding developments activities are on-going)

- large and low noise detectors
- actuators/mechanisms for refocusing

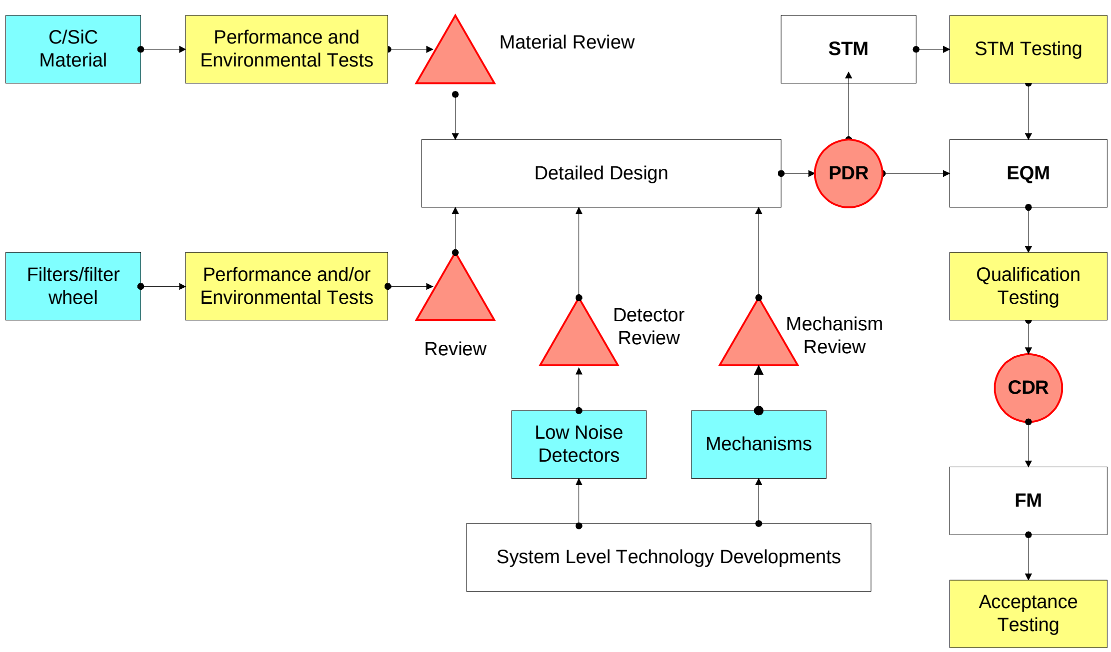


Figure 2.2-2: Technology Development Roadmap

2.3 Development Planning for Phases B and C/D

2.3.1 Work Breakdown Structure

The function oriented Work Breakdown Structure (WBS) is shown in Figure 2.3-1 below. The project is subdivided in management, product assurance, engineering, MAIT and procurement tasks. This WBS and the hardware breakdown shown in Figure 2.2-1 form the basis for the industrial cost estimate.

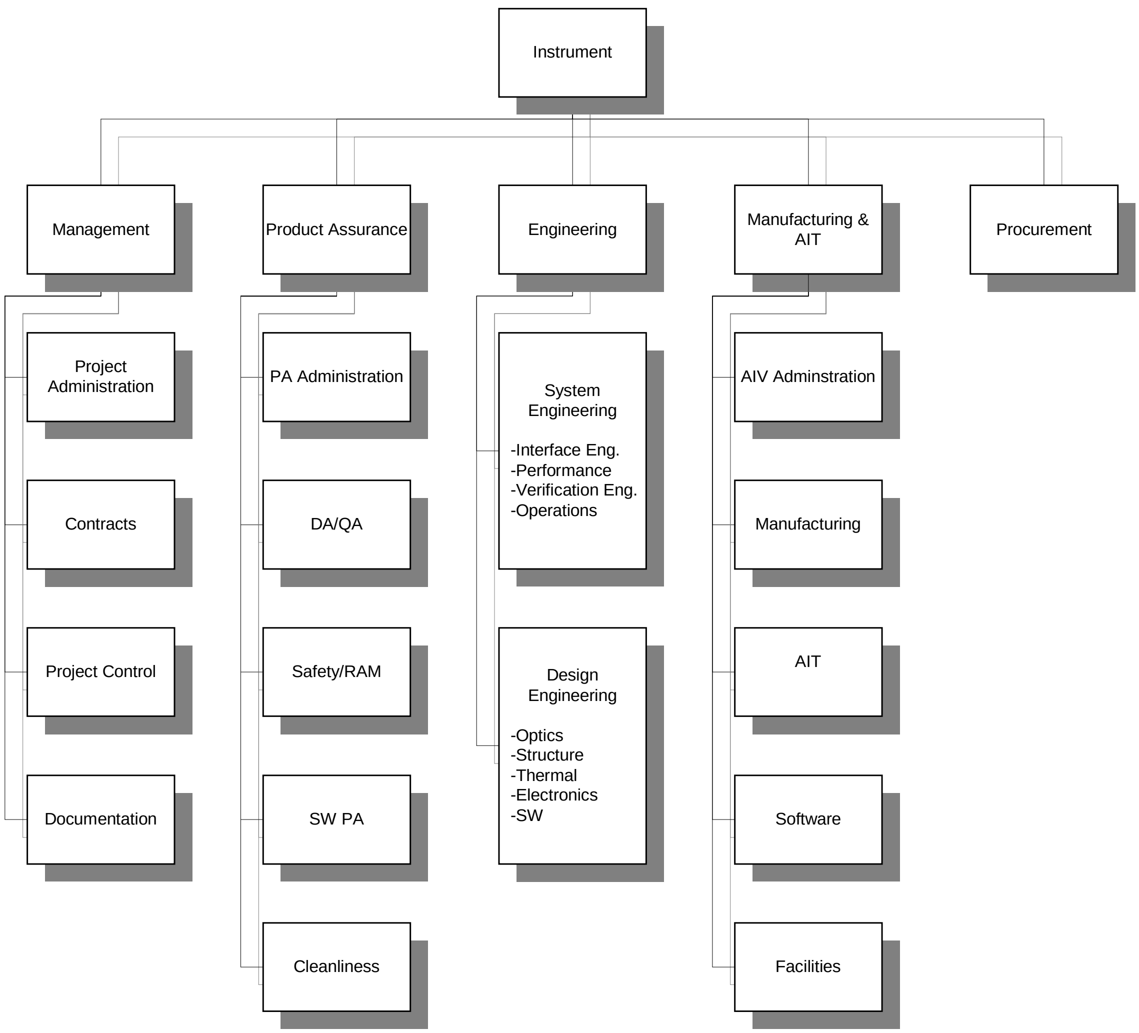


Figure 2.3-1: Function oriented Work Breakdown Structure

2.3.2 Development Planning

Two model philosophies have been considered for Phases B and C/D:

- **Standard model philosophy** (or standard development approach), according to a typical ESA space project and aiming for low risk
- **Alternative model philosophy** (or alternative development approach), trying to meet the NASA schedule

Standard Model Philosophy and Schedule

The standard philosophy is based on a typical (European) space project approach and shown in Figure 2.3-2. The development risk is minimized by building a set of prototypes and models: any design deficiencies identified on a lower level model can be eliminated on the subsequent higher level model. The sequential flow of models and associated learning steps will minimize potential risks for the flight model.

Besides technology breadboards and prototypes the following models are envisaged:

- Structural/Thermal Model (STM)
- Engineering Qualification Model (EQM)
- Flight Model (FM)
- Flight Spare

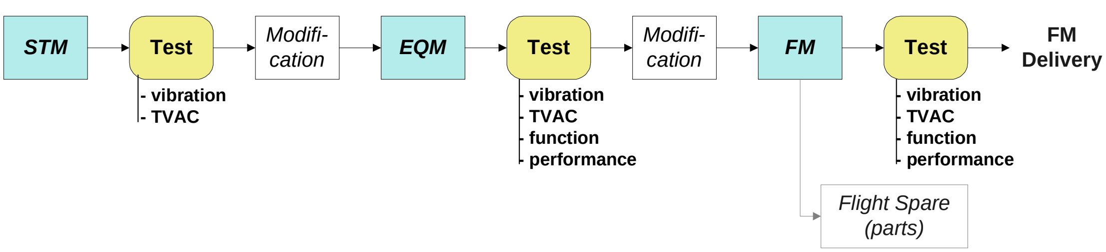


Figure 2.3-2: Standard Model Philosophy

The STM will be used to test the structural and thermal performance at low temperatures and after launch loads. Likely design modifications for the EQM will be derived. The STM will then be shipped to NASA for system level tests.

The EQM will be fully equipped and will undergo all performance and environmental tests on qualification levels. Design modifications for the FM will be derived, if necessary. The FM will be tested to acceptance levels only. The flight spare will consist of a set of instrument functional units and spare parts.

Drawback of this approach is the long development duration: the FM delivery will not be before end of 2007, see Figure 2.3-4. This delivery date is about 1.5 years later than scheduled by NASA.

Advantage of this approach is the identification of hardware problems at the earliest possible stages. This will allow to implement necessary design modifications and reduce the risk for the flight model performance.

Alternative Model Philosophy and Schedule

In order to meet the NASA need dates for the NGST instruments, the above presented „standard" schedule has to be reduced in time. This will lead to a reduction of models and a corresponding increase of risk.

Besides technology breadboards and prototypes, the following models are proposed:

- Structural/Thermal Model (STM)
- Optical Engineering Model (OEM)
- Proto-Flight Model (PFM)
- Flight Spare

The alternative model philosophy is shown in Figure 2.3-3 below.

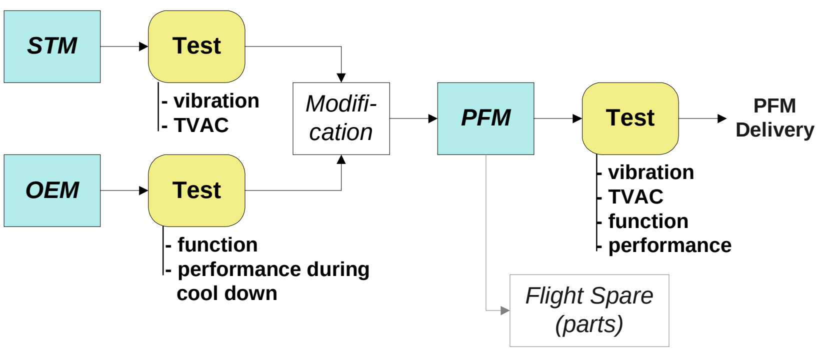


Figure 2.3-3: Alternative Model Philosophy

Even with a reduced development program the STM is still considered mandatory to test the performance of the large instrument structure at low operating temperatures and after launch loads. Necessary design modifications are likely and will be derived for the PFM. After testing the STM will be shipped to NASA for system level tests.

In parallel to the STM, an OEM will be equipped such that an opto-mechanical (and electrical) verification of the concept can be performed at ambient temperature and at moderately lowered temperatures. The OEM will undergo an accelerated performance and environmental test program. It cannot be expected that the OEM will provide satisfying performance at operational temperature, but its behavior during cool-down, together with the STM test results, will provide valuable inputs for PFM improvements.

The PFM will be the first instrument model to be fully tested at acceptance levels. The flight spare will consist of a set of instrument functional units and spare parts.

Major drawbacks of this approach are:

- the final impacts of the structural/ thermal and opto-mechanical modifications can not be clarified before PFM availability
- the first real optical verification of the instrument will be performed on the flight model

Although with this alternative approach the associated risk is higher than for the standard model philosophy, it nevertheless bears the potential to meet the requested NASA need dates.

2.3.3 *Schedule*

The development schedule for both the standard and the NASA compatible approach are shown in Figure 2.3-4.

Up to and including Phase B the schedules are identical. However, the short PFM delivery date of the NASA compatible approach has repercussions not only on the shorter procurements phase but also on previous phases. In this case the technology readiness has to be ensured at the beginning of Phase B and all manufacturing files should be finished at PDR (end of Phases B) to start immediate hardware realization at beginning of Phase C/D.

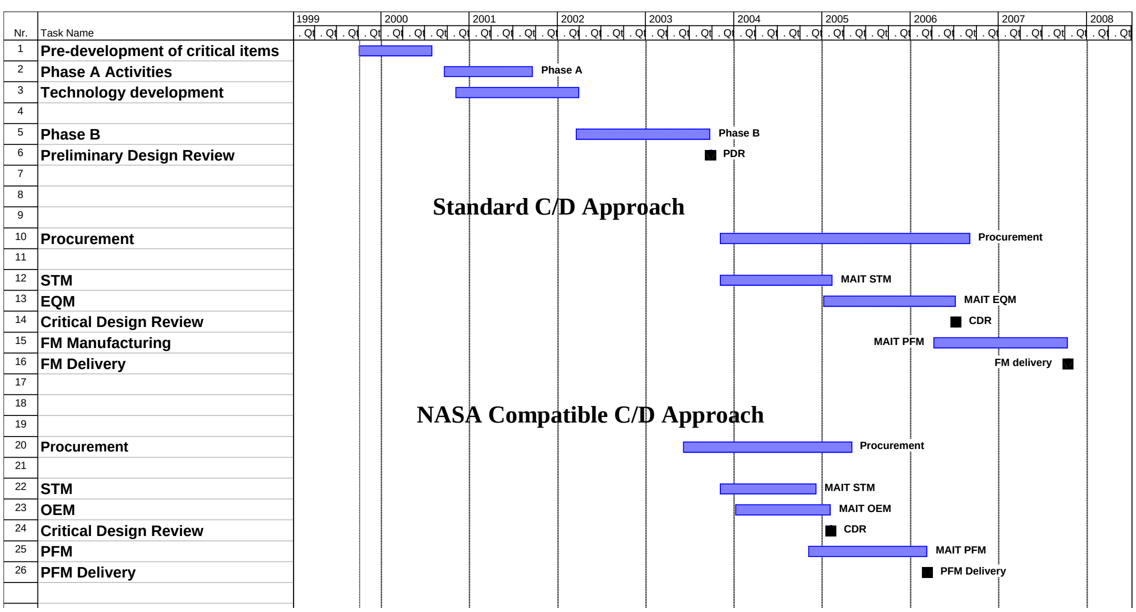


Figure 2.3-4: Proposed development schedule for both model philosophies

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/5/ NASA Exposure Time Calculator